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CONDITION OF THE HANGING WALL ABOVE THE ROCKBURST AREA AT QUIRKE MINE

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CONDITION OF THE HANGING WALL ABOVE THE ROCKBURST AREA AT QUIRKE MINE

by

D.G.F. Hedley*

ABSTRACT

During 1985 the hanging wall above the rockburst area at Quirke Mine fractured through to surface. Water inflow underground increased from about 1 to 19 L/sec, and there was a water loss of about 75 million litres from a beaver pond above the affected area.

The cause of the hanging wall fracturing and water inflow was an increase in the areal extent of pillar failure underground. In the western part of the rockburst zone the area of pillar failure increased from 300 x 400 m in August 1984 to 500 x 600 m by the end of 1985. This expansion was accompanied by 140 rockbursts of magnitude 1.2 to 3.5. Also, the overlying formations subsided into this zone reducing the horizontal confinement and allowing slippage along bedding planes and steeply-dipping structures.

The sequence and evidence of hanging wall fracturing are examined based on the pattern of rockburst activity, water inflow rates, results from diamond drilling from surface and computer models of stresses in the hanging wall.

Keywords: Rockbursts; Water inflow; Hanging wall fractures; Computer models.

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CONDITION DU TERRAIN DE RECOUVREMENT SITUÉ AU DESSUS DE LA ZONE DES COUPS DE TOIT À LA MINES QUIRKE

par

D.G.F. Hedley*

RÉSUMÉ

Au cours de l'année 1985, le terrain de recouvrement situé au dessus de la zone des coups de toit de la mine Quirke s'est fracturé jusqu'à la surface. L'entrée d'eau souterraine a augmenté, allant de 1 à 19 L/sec, ce qui a causé une perte d'environ 75 millions de litres d'eau à un étang de castor situé au dessus de la zone affectée.

La cause de cette fracturation du terrain de recouvrement et de cette entrée d'eau provient de l'augmentation de la superficie de détérioration des piliers souterrains. Dans la partie ouest de la zone des coups de toit, la surface de détérioration des piliers a augmenté, allant de 300 x 400 m en août 1984 à 500 x 600 m à la fin de 1985. Ce développement s'est accompagné de 140 coups de toit de magnitude variant entre 1.2 et 3.5. De plus, les formations susjacentes se sont enfoncées dans cette zone, réduisant ainsi le confinement horizontal et permettant le glissement des plans de stratification et des structures profondément inclinées.

C'est en se basant sur le profil d'activité des coups de toit, sur le taux d'infiltration d'eau, sur les résultats des forages au diamant à partir de la surface et sur les modèles informatisés portant sur les contraintes dans les terrains de recouvrement, que la séquence et les évidences de la fracturation du terrain de recouvrement sont examinés.

Mots-clés: coups de toit; entrée d'eau; fractures du terrain de recouvrement; modèles informatisés.

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INTRODUCTION

During 1985 several events occurred which were consistent with fracturing and/or caving of the hanging wall above the rockburst area in the east part of Quirke Mine. Water inflow which had been 1.3 L/sec in 1984 increased to 19.1 L/sec. Previously, the pattern of rockburst activity had progressively spread outwards. In 1985, rockbursts again started to occur in the central zone where the pillars had already failed in 1982. It was thought that these rockbursts were located in the hanging wall and could be caused by slippage along faults or shearing through intact rock.

To prove whether the hanging wall was caving, it was decided to put down a diamond drill hole from surface. An existing surface exploration borehole was located directly above the centre of the rockburst area. It was decided to utilize this borehole down to a depth of 346 m, then install a wedge and drill a new borehole until the caved zone was encountered, or the mine workings at a depth of 498 m.

Considerable difficulties were encountered in the exploration borehole and eventually drilling was abandoned at a depth of 254 m. However, sufficient information was obtained from the pattern of rockburst activities, drilling results plus water inflow data to establish that the hanging wall was fractured to surface.

SEISMIC ACTIVITY

Rockbursts first occurred in the eastern part of Quirke Mine in March 1982. Seismic activity has continued since that time with varying intensity. Since August 1982, an Electrolab microseismic system has been in operation which has greatly assisted in locating both major rockbursts and minor seismic events. However, the geophones are almost in a planar array which makes vertical resolution difficult.

Figure 1 is a plan view of the eastern part of Quirke Mine and the adjacent Denison Mine, showing the locations of the 140 rockbursts that have occurred since September 1984. In this report a rockburst is defined as a seismic event of sufficient magnitude to be detected by the Eastern Canada Seismic Network. The Geophysics Division of Energy, Mines and Resources Canada calculates the magnitudes of these events, which have ranged from 1.2 to 3.5 at Quirke.

The March 1982 rockbursts were located in the sill pillars on the 7 level just above a trial trackless area. By August 1984, it was estimated that the zone of pillar failure extended about 870 m on strike by 300 m on dip as shown in Figure 1. Some large pillars just to the north-east of the trial trackless area were holding back failure in this area. A number of roof falls were observed at the edge of the failure zone (no access to centre at that time). These falls were about 2.5 m thick and controlled by structural features bedding plane slips, thrust and normal faulting, and the more prominent joint sets. It was considered that the main roof was still spanning the affected area in August 1984.

Major rockburst activity in the pillars again occurred in September 1984 and continued almost continuously until April 1985, and sporadically after that. First the sill pillars on the 6 level directly north of the trackless area failed increasing the span on dip to 420 m. In February 1985 the 5 level sill pillars failed increasing the span to 520 m, and in August/September 1985 the 9 level sill pillars failed increasing the span to 600 m on dip. The affected area also expanded to the east and west, and there was a large concentration of rockbursts around the large pillars north-east of the trackless area. By the end of 1985 the zone of pillar failure extended about 1100 m on strike by 600 m on dip as shown in Figure 1.

In December 1984 one rockburst was located in the centre of the trial

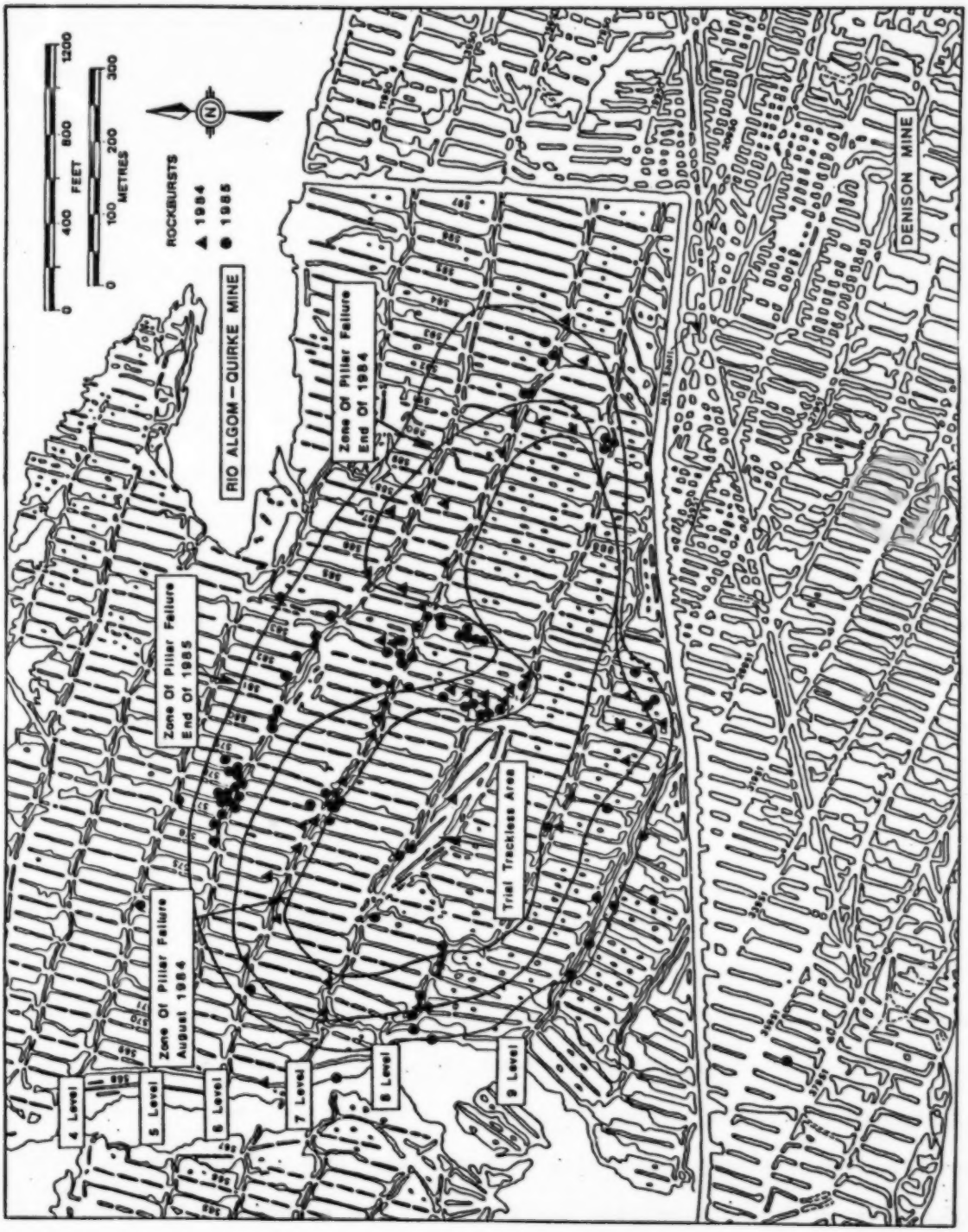

Fig 1 - Location of rockbursts at Quirke Mine in 1984/85.

trackless area. Visual observations in July 1982 had indicated that the pillars in this area had failed and it was suspected that the rockburst had occurred in the hanging wall. A mud-coated thrust fault is located 36 m above the orebody at this location and slippage could have occurred along this fault. During 1985 three more rockbursts occurred in the same area. In addition these events more or less line up in a straight line which suggests some structure may be involved. Also five rockbursts occurred around the 6 level sill pillars near 678 stope which had failed in September 1984. All these rockbursts were intermediate in size with magnitudes 1.6 to 2.2.

If these rockbursts did occur in the hanging wall then the first breakdown (December 1984) in the roof occurred when the partially supported span on dip was 420 m. This breakdown accelerated in February 1985, when the span increased to 520 m, and in September 1985 to 600 m. The average depth below surface in this area is about 500 m. It is interesting to note in Figure 1 that no rockbursts have been recorded at the centre of the eastern part of the rockburst zone. The partially supported span on dip is about 360 m in this area.

WATER INFLOW

During mining of the eastern part of Quirke Mine, no external water entered the mine. External water was first observed in January 1983 at a rate of 0.7 L/sec. This water came from the upper reef stopes, 40 m above the main reef in the east end of the mine, about 250 m north of Denison's No. 1 shaft in Figure 1. An argillite contact is about 3 m above the roof of these stopes and water was observed coming from this contact. This water migrated through fractures in the rock between the two reefs and flowed out through the 6 haulage level.

The water flow peaked at about 5 L/sec in May 1983, then gradually

declined to 1.3 L/sec in January 1985. During this month the water flow dried up and an identical flow rate appeared on the 7 haulage level. It is thought that rockbursts on the 6 sill level fractured through into the 6 haulage drift allowing the water to flow down the stopes into the 7 haulage level. In February 1985 water appeared in the 8 haulage level at an initial flow rate of 3 L/sec. Most of this water was observed running down 888 stope, which is identified in Figure 1.

Weirs were constructed on both the 7 and 8 haulage levels to measure these flow rates, which are plotted in Figure 2. There was a large increase in water inflow in both levels in April 1985. Subsequently, total flow rates fluctuated from 14.5 L/sec to 19.2 L/sec. During 1985, it is estimated that about 420 million litres of water entered the mine, which is almost the same amount of extra water pumped from the mine in 1985 compared to 1984.

Figure 3 is a surface plan above Quirke Mine showing the topography and an outline of the rockburst area underground. A beaver pond overlaps the rockburst area. Sometime between April 1985 (i.e., last time visited), and December 1985 (i.e., ice-up time), the water level in the beaver pond dropped by about 4 m as illustrated in Figures 4 and 5. This represents a water loss of about 75 million litres. Also shown in Figure 3 is the drainage area of the beaver pond. Rio Algom Ltd. keeps precipitation records at nearby tailings areas. During 1985 there was 94 cm of precipitation which represents an additional 110 million litres of water flowing into the beaver pond, assuming no evaporation. Consequently, during 1985 the total water potential from the beaver pond area is about 185 million litres compared to 420 million litres entering the mine. Hence there must be other sources of water ingress. Three can be identified:

a) The Serpent River lies just north of the mine, and the argillite formation outcrops in the river bed.

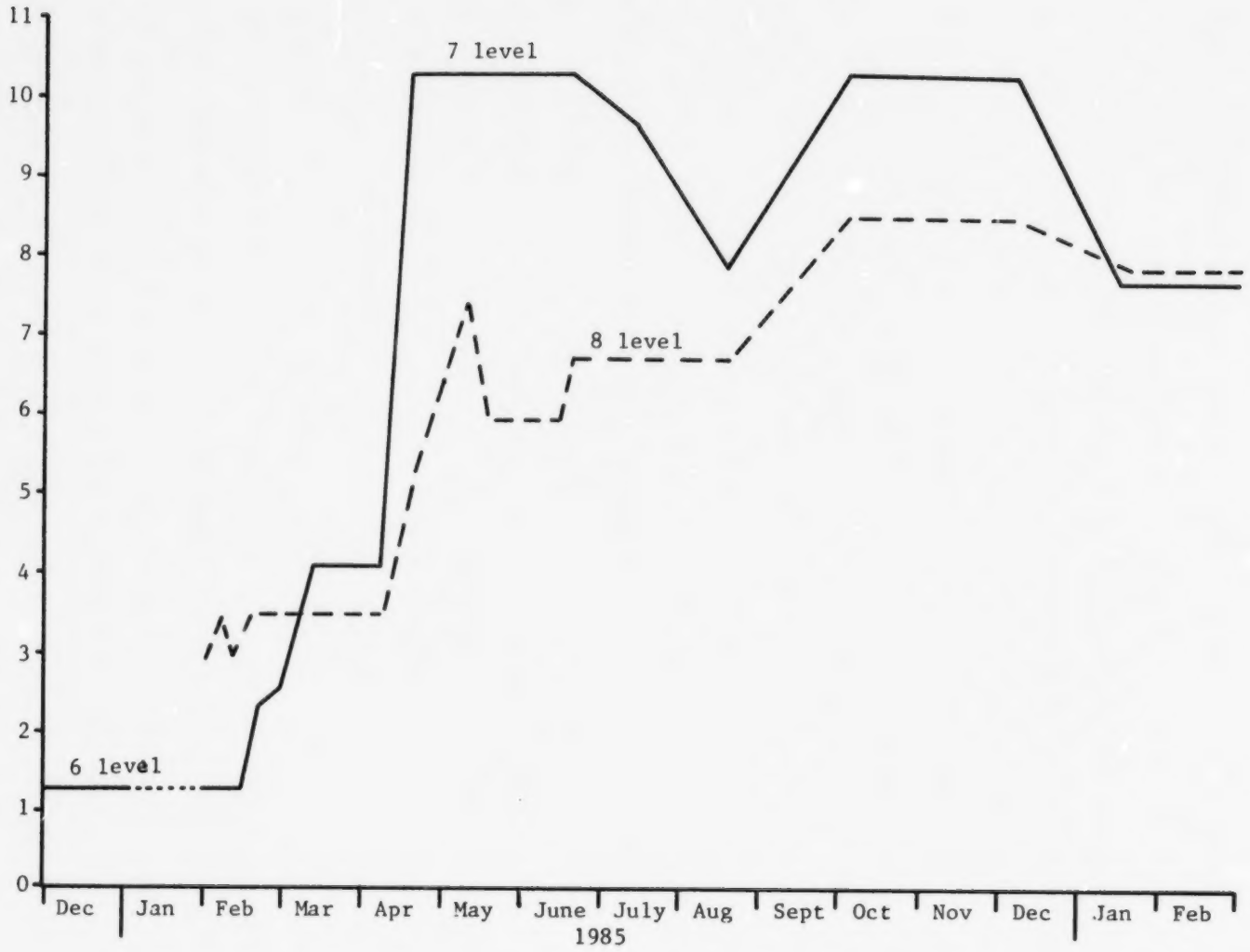

Fig. 2 - Water inflow from rockburst area.

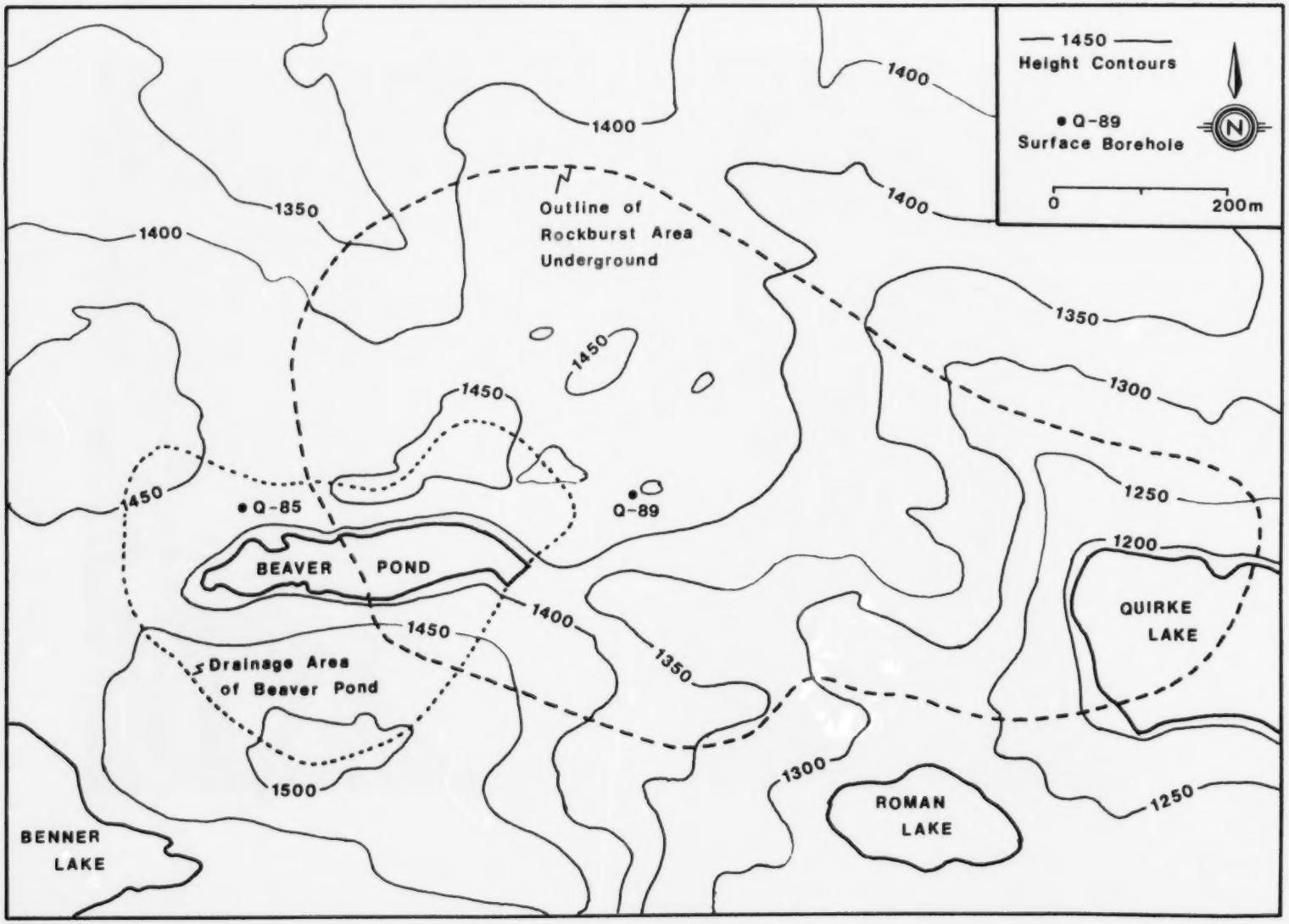

Fig. 3 - Surface plan above rockburst area at Quirke Mine.

Fig. 4 - Beaver Pond looking west.

Fig. 5 - Beaver Pond looking east.

b) Quirke Lake lies due east of Quirke Mine.

c) The hanging wall above the rockburst area could have fractured to surface making a much larger drainage area than just the beaver pond watershed area.

Rio Algom Ltd. have done chemical analysis on water samples from the 7 and 8 haulage drifts in an attempt to identify the source of the water. Reliable sampling is difficult due to contamination as soon as the water enters the mine working, and especially the haulage drifts. Notwithstanding, a fairly common feature was the relatively low concentrations of ammonia and nitrates which is not a characteristic of the water in the Serpent River or Quirke Lake. Moreover, water samples from the beaver pond showed similar low concentrations of ammonia and nitrates. Consequently, although the evidence is not conclusive, the most likely source of the water entering the mine is from fracturing to surface which has created a fairly large drainage area above the rockburst zone.

DIAMOND DRILLING

A diamond drill was brought on site in early March 1986 and positioned over borehole Q-89, as identified on the surface plan in Figure 3. This exploration borehole was drilled in 1963, and is directly above the trial trackless area and the centre of the rockburst zone. A cross-section through this borehole is shown in Figure 6, indicating the geologic formations. It was intended to utilize this borehole to a depth of 346 m in the middle of the Mississaugi Quartzite formation, then install a wedge and drill a new borehole until the caved zone was encountered or the mine workings at a depth of 498 m.

A geophone had been installed in borehole Q-89 in 1984, to improve the vertical resolution of the microseismic monitoring system. There was an

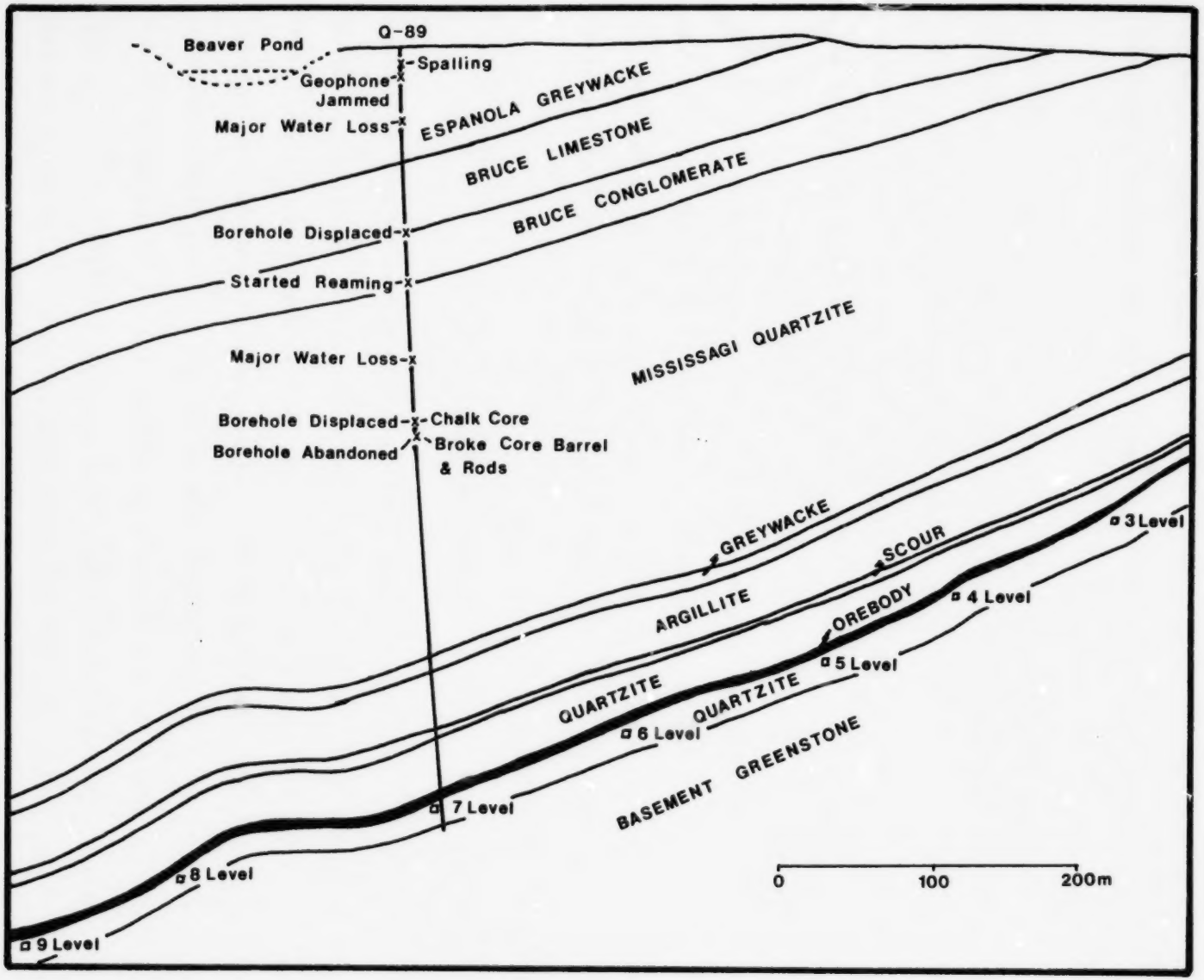

Fig. 6 - Cross-section through surface exploration borehole Q-89.

obstruction at a depth of 48 m beyond which the geophone would not pass. The water level in the borehole at that time was about 2 m below surface. Subsequently, the geophone became defective and an attempt was made to recover it in May 1985. However, it jammed again at a depth of 17 m below surface. Another unsuccessful recovery attempt was made in October 1985, and at this time water was encountered at a depth of about 10 m below surface. With the diamond drill on site, water was pumped down the borehole, but none came out at the collar indicating a direct connection to underground, which happened sometime between October 1985 and March 1986. No return water was a common feature and problem throughout the diamond drilling operations.

The depths at which problems occurred in the borehole are indicated on the cross-section in Figure 6, and briefly reviewed below:

1. Spalling encountered at a depth of 12 m, required grouting.
2. Geophone reamed out at 17 m, then drilled half a metre of rock before returning to the original borehole.
3. Restriction and severe water loss at 48 m. Installed plug and poured 10 bags of cement (sufficient to fill 180 m of borehole). When redrilling, cement encountered at a depth of 37 m. This was the only time that water from drilling came out on surface.
4. Drilling rods jammed at 126 m which is the contact of the conglomerate/limestone beds. Log from original borehole indicated 2 m of core loss at this location.
5. Installed wedge at 126 m and drilled past, but ended up in the original borehole. This is a remarkable coincidence and indicates a lateral displacement equal to the diameter of the borehole (i.e., 48 mm).
6. From surface to 126 m depth the drill rods had to be pushed down the borehole. Between 126 to 159 m the drill rods were free-falling.
7. Reaming had to start at 159 m depth which is the contact of the

limestone/quartzite beds.

8. Recovered 4 m of almost pure chalk at a depth of 244 m which must have percolated down from the overlying limestone beds.
9. From 245 m down experienced considerable difficulties drilling in the quartzite, with the bit going in and partially out of the original borehole. A limited amount of core recovery had an outline of the old borehole with up to 25 mm of lateral displacement.
10. Core barrel snapped at 265 m depth. A second wedge was installed at 258 m and reamed to bottom of wedge, at which point the drill rods snapped with 10 m of rods permanently stuck in the borehole.
11. Installed third wedge at 247 m depth, reamed past wedge and recovered 7 m of quartzite core.
12. Wedge dislodged making it impossible to get the drill rods past and the drilling was abandoned.
13. After setting the second and third wedge it was observed that the maximum water level in the borehole was at a depth of 210 m.

Although the drilling was unsuccessful in establishing a caving line (unless this was at a depth of 265 m where the core barrel snapped) it did indicate that lateral displacements had occurred to the original borehole. Previous wedging and re-drilling of surface exploration boreholes at Quirke Mine had encountered no problems.

Subsequently, while pouring dye down Q-89 borehole, it was found that air was being sucked into the borehole with a negative pressure of 9 cm water gauge. Also water could be heard running down the borehole. Again, this indicates a direct connection with the underground working, even though plugs and wedges had been installed in the borehole. Over a four-week period the air and water flows decreased and eventually stopped, presumably due to the deposition of chalk percolating from the limestone formations. Other surface

exploration boreholes were checked for air and water flow, and it was found that borehole Q-85, just north-west of the beaver pond in Figure 3, had water flowing in it. Surprisingly, dye placed in both borehole Q-89 and the beaver pond could not be traced underground, perhaps due to the dulution factor or filtering.

During spring run-off, in late April 1986, there was no surface water accumulation in ditches and depressions above the rockburst area, although there had been in previous years. However, there was surface water accumulation outside of the rockburst area.

COMPUTER MODELLING

Both Steffen, Robertson and Kirsten Inc. for Denison Mines Ltd., and Golder Associates for Rio Algom Ltd. have run computer models to estimate the spread of the rockburst area at Quirke Mine. Golder's NFOLD model was used in both cases. This model incorporates the post-failure characteristics of the pillars. The loading modulus, peak strength, unloading modulus and residual strength are specified for a variety of pillar sizes.

The model uses an iterative process to calculate stresses and displacements. When a pillar exceeds its peak strength, load is redistributed onto the remaining pillars. As additional pillars fail the redistribution continues until a stress equilibrium is achieved.

The model size was very large encompassing an area 1645 m on strike by 1465 m on dip. It covered all the mine workings at Quirke and Denison mines shown in Figure 1. The abutments and large pillars (e.g., boundary pillar) were modelled as they were. For the small pillar areas an equivalent extraction ratio was modelled. After a number of trial runs a reasonable match was achieved between the observed area of pillar failure and that predicted by the model.

The initial computer model was based on an infinite depth assumption, but later models by Golder Associates did incorporate the surface. In addition, the stresses in the hanging wall were calculated for specific points. Figure 7 shows the direction and magnitudes of the principal stresses in the hanging wall along cross-section AA, which is identified in Figure 1, and passes through the centre of the pillar failure zone.

The model shows that the pillars between the 4 and 9 levels have failed and are at residual strength, which agrees with the observations. The sub-horizontal stresses in the hanging wall follow an arch-type configuration above this failure zone which is consistent with the formations subsiding into this zone. Above the failure zone the sub-vertical stresses are very low, all the way to surface. These stresses clamp the bedded formation together. With lower clamping forces it is easier for slippage to occur along the bedding contacts, which is what the diamond drilling indicated.

DISCUSSION

The hard evidence of breakdown of the hanging wall above the rockburst area at Quirke Mine is:

a) drop in water level in the beaver pond;

b) increase in underground water inflow in 1985;

c) lateral displacement of the exploration borehole;

d) flow of water and air down the borehole.

This established that there is a direct connection between surface and underground, and that movement is occurring in the hanging wall.

More circumstantial evidence of hanging wall breakdown is:

a) rockbursts are again occurring near the centre of the rockburst area where the pillars have already failed;

b) chemical analysis showed that the water entering underground is similar

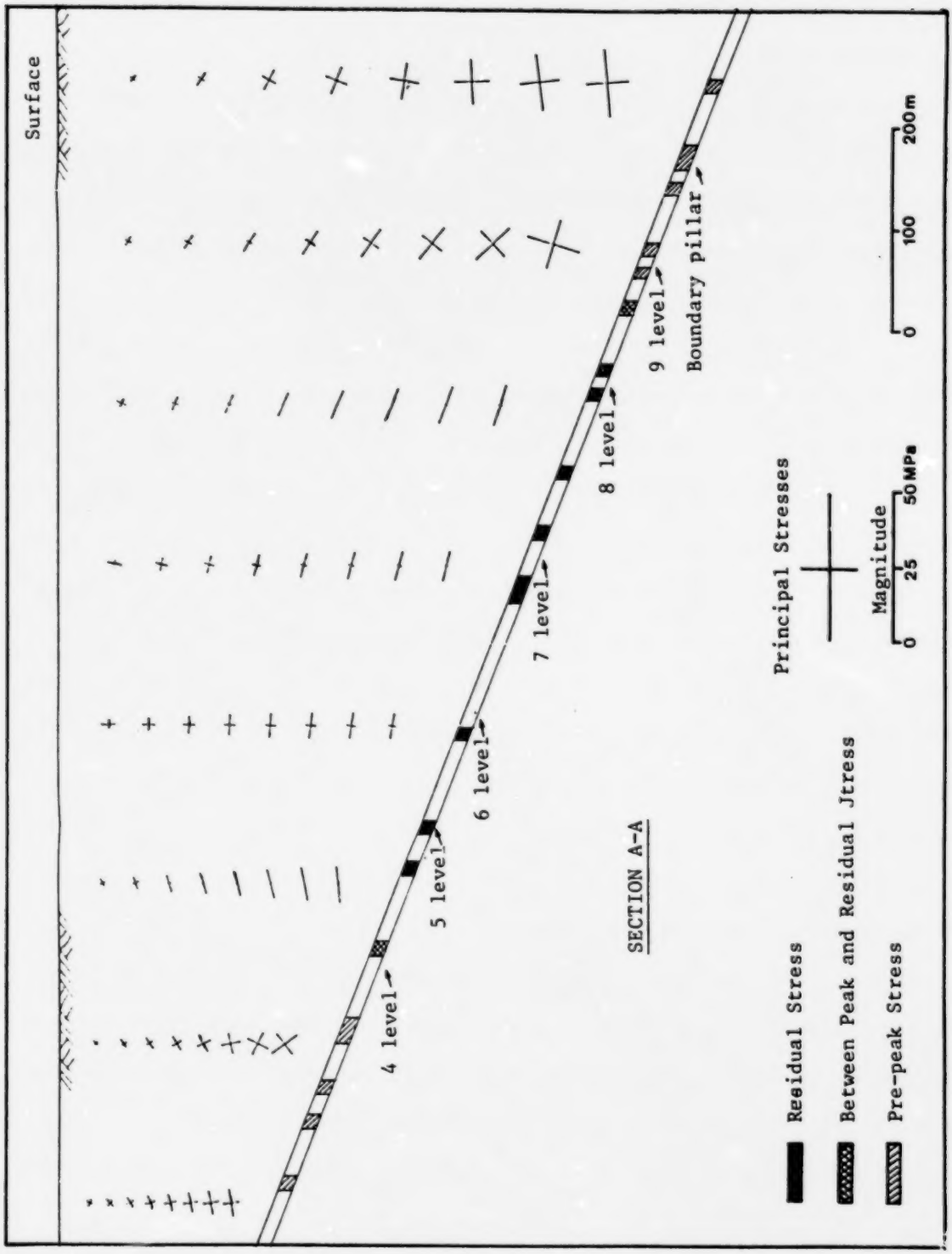

Fig. 7 - Hanging wall stresses above rockburst area (courtesy R. Hammett, Golder Associates).

to that in the beaver pond rather than the water in Quirke Lake or the Serpent River.

c) lack of surface water above the rockburst zone during spring run-off.

All this evidence points to general fracturing of the rock mass above the western part of the rockburst area. Water is migrating from surface to underground along bedding plane contacts and probably steeply-dipping joint sets and minor faults. There is no single geological structure in the vicinity which could account for all the water inflow. Caving (as distinct from fracturing) has probably occurred immediately above the orebody, but has not progressed up 230 m where the diamond drill hole was abandoned.

Breakdown of the hanging wall was probably initiated when the partially supported span on dip was 420 m and accelerated when the span increased to 600 m. As the span increased the overlying beds subsided into the openings similar to a beam, inducing a tensile stress on the lower member. (In actual fact the pre-mining horizontal stress is compressive and the subsiding of the beds would cause a reduction in this compressive stress). Eventually, the reduction in horizontal confinement would allow movement along the steeply-dipping faults and joint sets. The rockbursts of magnitude 1.6 to 2.2 M_N, which occurred in the central zone, were probably caused by slippage along these structural features. If the mechanism of hanging wall failure had been by shearing near the edges, then the rockburst locations would be different, and the magnitudes would probably be much greater. This gradual breakdown of the hanging wall will probably continue and be seasonal in nature, depending on the water inflow which is lubricating the structural features.

Further investigations are planned to clarify some of the uncertainties, including:

a) a seismic reflection survey from surface and delineate a caving zone, if it exists;

b) installation of a new seismic monitoring network on surface utilizing triaxial geophones which should give more accurate vertical resolution of seismic events using P and S wave arrivals;

c) evaluation of satellite photographs of the area to see if there has been any change in the surface drainage patterns since 1984;

d) drilling of a completely new diamond drill hole from surface to establish if there is a caving zone.

ACKNOWLEDGEMENTS

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